Development of Contact Model of a Robot Soft Finger for Power Grasping and Determination of Its Contact width

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***Abstract*-A contact model of a robot soft hand is developed for power grasping based on the geometrical relationship between contact parameters such as deformation, contact width and touch angle. The proposed nonlinear cylindrical soft finger deforms on the application of normal load and contact surface and touch angle grow correspondingly. The deformation and contact width are related to touch angle. The force relationship between contact parameters and geometrical data is then derived. The developed analytical model enables to determine the total contact force at the contact surface during manipulation. The validation of the model is done by conducting experiments with artificial fingers of different hyper elastic materials. The contact area is determined by measuring contact width experimentally. The developed soft finger model and its force function can be usefully applied to soft fingered object manipulations in future.**

***Index Terms*-hyper elastic, power grasping, precision grasping**

I. INTRODUCTION

For the past two decades, elaborate research has been done on the development of multifingered robot hand, which is employed as prosthetic hand or in humanoid robots. Power grasping and precision grasping are two areas in which the former relates to the application of robots carrying heavy loads. Many models and algorithms have been developed for manipulating objects with multifingered robot hand. In the recent years, research is focused towards the manipulation in which the robot fingers are made of soft material. Identification of suitable soft material as substitute for the human skin is a tedious and the effect of deformation of soft finger and/or object is a common issue in the development of such robot hand. The development of soft fingers is a fundamental area in soft manipulations. Related to the modeling of a soft hand Xydas et al [1][2]. developed a contact model and studied soft finger tip contact mechanics using FEM and validated the results by experiments. Byoung-Ho Kim et al [3]. analyzed the fundamental deformation effect of soft finger tip in two fingered object manipulation. Takahiro Inoue et al [4]. focused on formulating elastic force and potential energy equations for the deformation of fingers which are represented as an infinite number of virtual springs standing vertically. Elaborate research has been done on soft finger tip manipulations but only a few attempts have been made on power grasping. Analytical model for force distribution in power grasps has been developed by Mirza et al [5]. Ismaeil and Ellis [6]. developed a method for calculating additional grasping force required for stable power grasping of objects. Toru Omata et al [7]. attempted to determine the static indeterminacy of the grasp force which is a fundamental problem in power grasping if static friction is considered in the contact points. A simple contact model as applied to power grasping has been developed in this paper and force-deformation relationship has been formulated. The geometrical relationship between deformation and contact width is first proposed. The total contact force which is based on the contact parameters, geometrical data and material property is then found by using the compressional strain mechanism. The contact width and deformation are measured experimentally and the model is validated.

II. DEVELOPMENT OF A SOFT FINGER AND GEOMETRIC ANALYSIS

Power grasp is characterized by multiple contact points between the grasped object and the surfaces of the fingers and palm. It maximizes the load carrying capacity of the grasping system and is highly stable because of the enveloping nature of the grasp. Generally, the contact between the object and cylindrical soft finger is made by a line contact and soft finger correspondingly deforms during the manipulation process. It then forms a contact surface area that depends on the applied normal load.

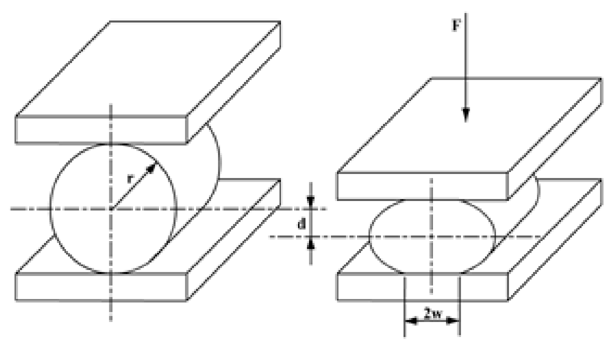

Figure 1. .Model of a nonlinear elastic cylinder making contact with a flat surface under a normal force F

DOI: 01.IJPIE.02.01.117

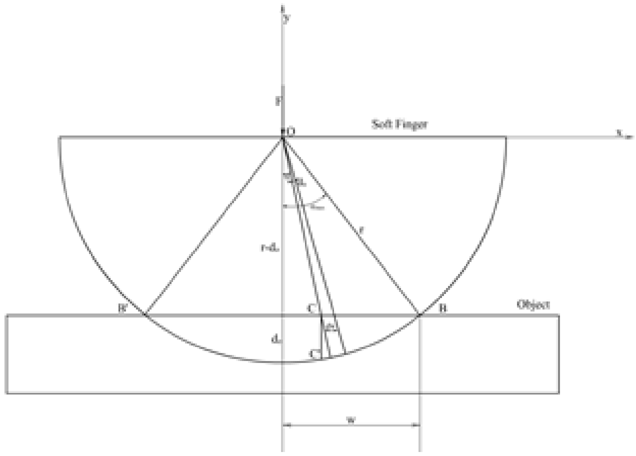

Figure 2. Model of a cylindrical soft finger pressed against a rigid plane. The contact surface area is assumed to be rectangular.

When a cylindrical finger comes into contact with a flat surface, width *(2w)* is established. The deformation of the finger is *d* (Fig.1). The Fig.2 shows a cylindrical soft finger of radius *r* and length *l* pressed against a rigid object. Let an arbitrary point C make an angle α and its *x* position C_x is given as

$$C_x = (r - d_0).\tan\alpha \quad (1)$$

Relation of a circle is given by

$$x^2 + y^2 = r^2 \quad (2)$$

Combining (1) and (2), y position C_y is represented as

$$C_y = \sqrt{r^2 - (r - d_0)^2 \tan^2\alpha} \quad (3)$$

y- directional length $\overline{CC}'$ is given by

$$\overline{CC}' = C_y - (r - d_0) \quad (4)$$

$\overline{CC}'$ is the deformation at a point on the contact surface of the soft finger.

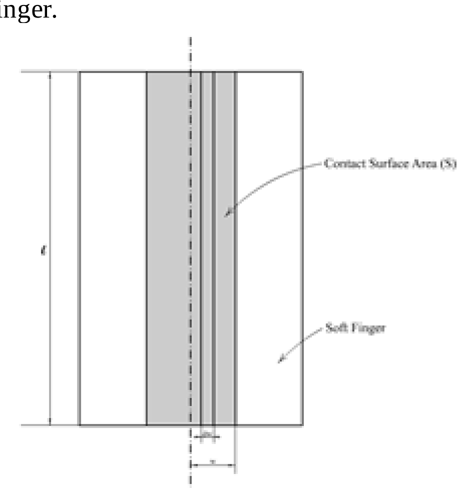

Figure 3. Contact Surface Area

When a force is applied over the finger, it deforms to d_0 and its corresponding half contact width and maximum touch angle are denoted as *w* and α_{max} .

Touch angle $\alpha_{max} = \tan^{-1}\sqrt{\dfrac{r^2 - (r - d_0)^2}{(r - d_0)^2}}$ (5)

Half contact width $w = (r - d_0)\tan\alpha_{max}$ (6)

A small change in the contact width is given by

$$dw = \frac{(r - d_0)}{\cos^2\alpha} d\alpha \quad (7)$$

A small increased contact surface due to the deformation dS is given by

$$dS = dw\ l \quad (8)$$

III. MODELING OF A SOFT FINGER

Considering a unit area within the contact region of a cylindrical soft finger, force relation is derived as follows.

Stress $\sigma \equiv \dfrac{F}{S}$ (9)

where F and S are contact force and area of contact respectively.

Pressure acting on the contact surface is defined as

$$P \equiv \frac{F}{S} \quad (10)$$

When a small compressive force is applied, the radius of the finger along y axis decreases but, contact width increases. The fractional change in the radius along y axis can be defined as the compressional strain.

Compressive strain $e = \dfrac{\Delta r}{r}$ (11)

where, $\Delta r = d_0$

By using modulus of elasticity, the force relation can be expressed as

$$F = E\frac{\Delta r}{r}S \quad (12)$$

Combining (10) and (12)

$$P = E\frac{\Delta r}{r} \quad (13)$$

The total contact force at the contact surface can be obtained by integrating the force distribution of the soft finger.

$$f_c = \int_0^{\alpha_{max}} P.dS \quad (14)$$

$$f_c = \int_0^{\alpha_{max}} E\ \frac{\Delta r}{r}\ dS \quad (15)$$

$$f_c = \int_0^{\alpha_{max}} El\ \frac{d_0}{r}\ \frac{(r - d_0)}{\cos^2\alpha}\ d\alpha \quad (16)$$

$$f_c = E.l\ \frac{d_0(r - d_0)}{r}\int_0^{\alpha_{max}} \sec^2\alpha\ d\alpha \quad (17)$$

DOI: 01.IJPIE.02.01.117

$$f_c = E.l\ \frac{d_0(r-d_0)}{r}\left[\tan\alpha\right]_0^{\alpha_{\max}} \qquad (18)$$

$$f_c = E.l\ \frac{d_0(r-d_0)}{r}\tan\alpha_{\max} \qquad (19)$$

Substituting 5 in 19, we get

$$f_c = E.l\ \frac{d_0(r-d_0)}{r}\sqrt{\frac{r^2-(r-d_0)^2}{(r-d_0)^2}} \qquad (20)$$

Hence contact force depends on the modulus of elasticity, radius, length of the finger and deformation. The touch angle (α) is 0º when there is no contact between the object and the finger and grows correspondingly as contact width grows. From (20),

$$(r-d_0) = \frac{f_c r}{Eld_0 \tan\infty_{\max}} \qquad (21)$$

Substituting (21) in (6),

the $\text{Contact width} = \frac{2 f_c r}{Eld_0}$ (22)

and the contact surface area is

$$\text{Contact Area} = \frac{2 f_c r}{Ed_0} \qquad (23)$$

IV. EXPERIMENTS

Fingers of size 18 mm diameter and length 100 mm were prepared from Silicone 401/70, Neoprene (W) and Viton E-60 (Supplied by M/s. Aerospace Engineers, India). The Fig. 4 shows the photographic view of developed artificial fingers. The objective of the experiment is to investigate the influence of material properties and the growth rate of contact width. In order to validate the developed contact model, the experiment was carried out in compression testing machine (KIC 10T, supplied by KALPAK Instruments and Controls). The maximum load capacity of the machine is 10kN and 0-1000N load range was used for the experiment. An arrangement was made with two plates and the finger was placed between them. It is interfaced with IBM PC with Windows based software for Online Data acquisition to PC as well as Data analysis. A thin oil film was introduced on the finger. A recording paper was introduced in between finger and the supporting plate. The thickness of the paper is very small and has negligible effects on the contact area. The load was applied gradually upto 1000N and load-deformation plot was obtained. The ideal finger will assume the entire contact area upon the application of the normal force, and the contact area will not change with subsequent increase of normal force. Such ideal soft finger may not exist, although human fingers behave quite close to such ideal soft finger in contact [8]. The contact widths of the finger for various values of applied normal loads were measured from the recorded finger prints. The finger prints were scanned using hp Scanjet G 3010 scanner. The software Motic Images Plus version 2.0 was used to measure the contact width of the image. The software has the option by which the linear measurement between two end points of the print could be found. The Fig. 5 shows the procedure followed to measure the contact width produced by fingers.

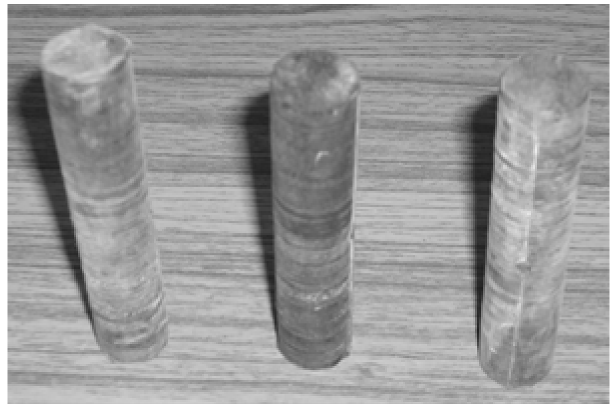

Figure 4. Developed Artificial Fingers

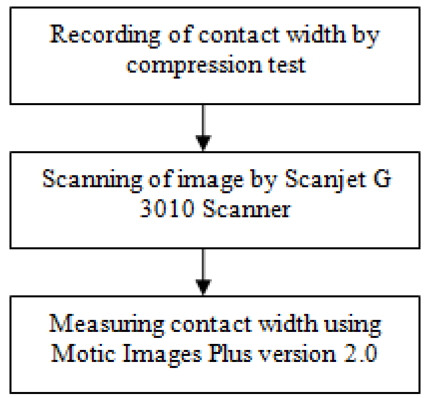

Figure 5. Determination of contact width

The test was conducted three times for each material and only the mean values of deformation and contact width were considered.

V. RESULTS AND DISCUSSION

The Fig.6 shows the deformation of fingers upto 1000N of load. Neoprene has high deformation, Viton has less deformation and Silicone has moderate deformation. For the load of 1000N, Neoprene produces 5.1mm, Viton and Silicone produce 2.96mm and 3.99mm of deformation respectively. The contact width is computed analytically using the measured deformation. The Fig. 7 shows the semi contact width of different fingers found analytically and experimentally. The semi contact width is 5mm, 2.6mm and 3.6mm at 1000N for Neoprene, Viton and Silicone respectively. The good agreement is found between the experimental results and analytical result with the deviation from 1% to 2.7%. Neoprene produces more contact width, where as Viton and Silicone produce less and moderate contact width respectively. It is known that the gripping force of the finger is determined by $f_g = \mu f_n$, where f_g is the gripping force, μ is the coefficient of friction of the finger contact surface against the part surface. f_n is the normal load acting on the finger. It is apparent that the increase in contact surface area makes the finger to handle the object with less power input. It is

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also known that the soft finger conforms to the object during the object manipulation. The contact area of fingers obtained from experiment is plotted in Fig.8. It is found that the contact area grows nonlinearly as load increases. It is found from the study that soft finger is needed for the robotic object manipulation. It is also known that power grasping is suitable for high load carrying capacity. It is understood from the experiment that the developed finger could produce more contact surface area. Hence it could conform to the object easily and suitable for developing robot soft hand.

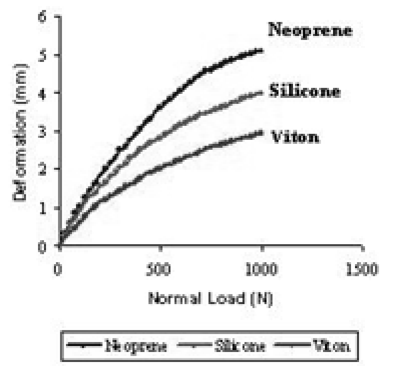
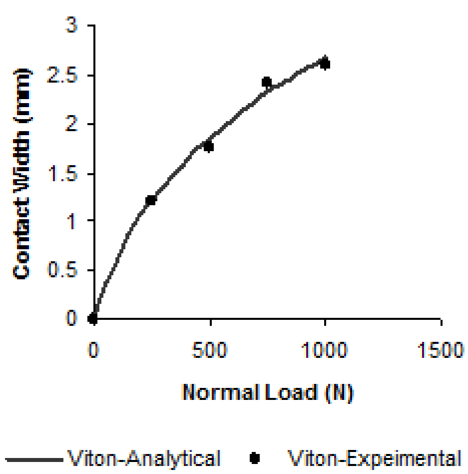
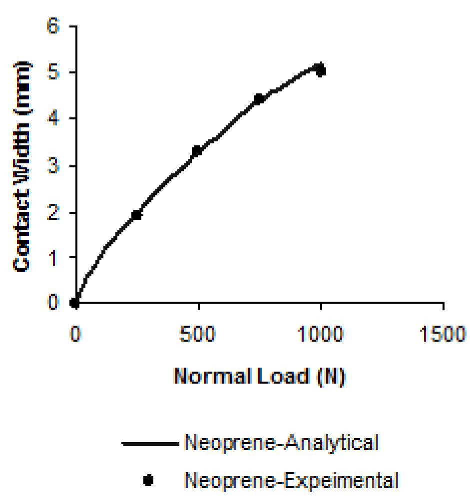


Figure 6. Normal Load Vs Deformation





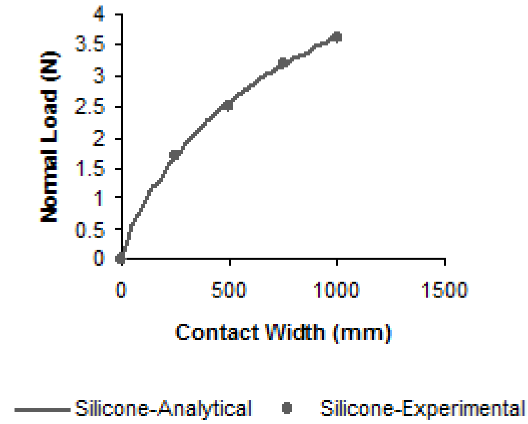


Figure 7. Normal Load Vs Contact Width

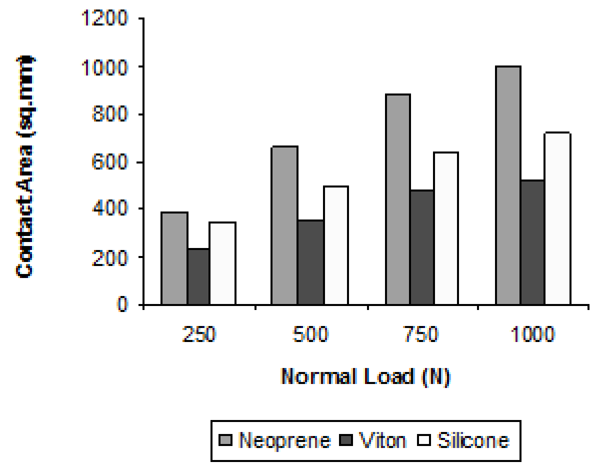


Figure 8. Contact area of Soft Fingers obtained from Experiment

VI. CONCLUSION

A cylindrical shaped soft finger for the power grasping is modeled and a nonlinear force function of the finger according to the deformation is derived by considering the force distribution in the contact surface. The analytical relationship relates contact width, deformation and touch angle using geometrical relationship. The experiment is conducted with fingers of three soft materials Viton, Neoprene and Silicone and the load-deformation curve is plotted. The half contact width is computed using the measured deformation and plotted. The developed contact model is validated by comparing the measured contact width with analytical result and only 1 to 2.7% of deviation is observed. The contact area of soft fingers found from experiment is also presented. The neoprene finger is comparatively softer than Viton and Silicone, where as Viton finger is the harder than other two. The developed soft finger model can be applied in multifingered robot hand for real life applications in future.

DOI: 01.IJPIE.02.01.117

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DOI: 01.IJPIE.02.01.117